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CAPITAL COEFFICIENTS IN MINERAL AND METAL INDUSTRIES

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This paper describes the methods and results of the Inter-Industry Analysis Branch, Bureau of Mines studies of capital coefficients in mining, mineral processing, and allied metal industries. The end product of the studies is a set of quantitative measures called "capital coefficients" which relate the detailed investment expenditures for a composite or average plant in the industry to a unit increase in capacity. In the course of deriving these coefficients both quantitative and qualitative descriptions of the investment process were examined in each of the industries. However, these studies have been conceived as applying ultimately to the theoretical context supplied by a dynamic interindustry model so that a number of aspects of the investment process and capital structure of industries, such as the role of expectations, cyclical impacts, and the effects of differential market structure, are not studied.

A dynamic interindustry model imposes some limitations on the range of problems which may be included in a study of investment behavior. There seems to be an inclination on the part of casual critics of the interindustry technique to infer that the coefficients used in the models (both flow and capital) are derived and used in a purely mechanical manner. In another place the erroneous character of these inferences concerning the flow coefficients has been examined[1]. To forestall like criticism of the studies of capital coefficients it is appropriate to set forth some of the theoretical problems of concept and method which have been encoun-

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Note: At the time this paper was presented, the author was Chief, Inter-Industry Analysis Bureau of Mines. The research described in this paper is the result of work performed by members of the staff of the Inter-Industry Analysis Branch. Their work is cited in the reports listed in this paper. In addition there are several who in particular have contributed materially to the concepts and methods described herein. Among them are Harold Barnett, Sidney Sonenblum, Pierre Crosson, William Vogely, and Gregory Zec.

[1] Frederick T. Moore, "A Survey of Current Interindustry Models," *Input-Output Analysis: An Appraisal,* Studies in Income and Wealth, Volume Eighteen, Princeton University Press for National Bureau of Economic Research, 1955, pp. 215–251.

tered in these studies. The limitations of these studies are not that mechanical *ad hoc* methods have been employed, but primarily that imperfections in the data set arbitrary limits to the theoretical hypotheses which could be explored.

Conceptual and Methodological Problems in Studying Capital Expansions

Some General Conceptual Matters:

The studies of capacity expansion in the mineral and metal industries culminated in a single set of capital coefficients, each of which indicated the dollar purchases from a supplying industry per unit increase in capacity (in physical terms) for a composite or average plant. A single set of coefficients for each industry normally meets the requirements for a dynamic interindustry model[2]; but such a set of coefficients describing the capital-to-capacity relationship for an industry imposes severe limits on the form of that relationship. It implies that the principles of additivity and divisibility apply here in the same manner as has been applied in usual production theory[3]. Specifically the principle of divisibility states that if x units of capacity are achieved by capital inputs A_1, $A_2, \ldots A_n$, then kx units of capacity can be achieved by capital inputs kA_1, $kA_2, \ldots kA_n$; thus there can be no economies of scale.

This initial (perhaps unfavorable) presentation of the form in which the results are stated is not too serious. A dynamic interindustry model does not actually require the use of a single invariant set of capital coefficients for each industry. In our studies the analysis has been broadened to include the effects of a variety of the factors which affect capital structure. In the latter part of this paper the individual industry studies are discussed very briefly, but with an emphasis upon the differences in the coefficients occasioned by the introduction of additional concepts. In the appendix tables there are several sets of coefficients for certain of the industries as well.

A priori it seems necessary to consider the impact of a number of factors affecting capital expansions. Among these factors are: the

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[2] J. L. Holley, "A Dynamic Model: 1. Principles of Model Structure," and "A Dynamic Model: Part 2. Actual Model Structures and Numerical Results," *Econometrica*, October 1952 and April 1953, respectively.

[3] T. Koopmans, "Analysis of Production as an Efficient Combination of Activities," *Activity Analysis of Production and Allocation*, Cowles Commission Monograph 13, 1951, Chap. III.

form in which the capital expansion takes place; the scale of the expansion; the existence of alternative production technologies; the variation in the measurement of capacity as product-mix changes. Furthermore, as in any empirical study, imperfections in the data raise additional problems in measurement and interpretation. These essentially were the type of factors considered in analyzing the costs of capital expansions. This list does not exhaust the possibilities of factors which might have been considered. Among those not considered are entrepreneurial planning horizons, interest and other financial costs, the effects of cyclical conditions, and the existing or expected state of demand. In a few cases in which it was applicable, the effects of market structure in the industry have been taken into account. For example vertical integration in the aluminum industry (including bauxite mining, alumina, aluminum reduction, and aluminum rolling and drawing) appears to have some effects on capital structure by permitting a better meshing of plant capacities from one stage of production to the next. Although it is dangerous to generalize on this point, it appears that an integrated firm uses a smaller total capital expenditure per unit of product than a set of nonintegrated plants.

No attempt has been made to cover the range of problems discussed by F. and V. Lutz in their study of the investment policy of a firm[4]. Nevertheless two aspects of the time dimension have been surveyed. It was not our purpose to decide when or under what conditions investment decisions would be made but only what is possible within the constraints imposed by technology. Consequently an attempt was made to measure minimum capital input lead times in each of the industries. The lead time refers to the period between the installation of equipment or construction and the point at which production begins (or alternatively, the point when the full capacity of the new expansion is attained). A different aspect of the same problem occurs in the handling of secondhand equipment. Since the value of a durable good is the present value of the future product streams which it is capable of begetting, the problem could conceivably have been handled in two ways. The remaining useful life, i.e. the future product stream, of the secondhand equipment could be contrasted with that for new equipment, and the denominator in the capital-to-capacity ratio could have been adjusted accordingly. It can be said categorically that this is an

[4] Friedrich and Vera Lutz, *The Theory of Investment of the Firm*, Princeton University Press, 1951.

infeasible procedure. Since capacity in the capital-to-capacity ratios in these studies refers to the annual capacity of which the plant is capable, the alternative was to consider all expenditures as having been for new equipment (reactivations of idle plant and conversions are treated as special cases). In future expansions in the industry, adjustments can be made in these capital coefficients based upon a knowledge of the supply of secondhand equipment available.

Marginal versus Average Coefficients

The capital coefficients in these studies are designed to represent marginal rather than average conditions. This choice was dictated by several considerations. First, a primary use of the coefficients is to represent the impact of demand upon supplying industries as capacity is expanded. For this problem it is the incremental amounts of required capital equipment which are important. Second, it is necessary and desirable to show the different patterns of capital inputs associated with the production methods available in the industry. For example, in zinc smelting and refining there are four different production methods: electrolytic, electrothermic, vertical retort, and horizontal retort. At the present time the largest single part of industry capacity is in horizontal retorts. In future expansions of the industry, however, it is clear that one or more of the first three processes will be employed and that the horizontal retort process will become relatively less important. In order to reflect this development, marginal capital coefficients giving greater weight to the first three methods are appropriate; average coefficients would give undue weight to the coefficients for the horizontal retort process. A third reason for concentrating on marginal rather than average coefficients concerns the (hypothesized) form of the function relating capital and capacity. If the function is linear and nonhomogeneous, marginal coefficients will be different from average coefficients. The example just mentioned of differing technologies is a case in point. If the function is regarded as basically nonlinear in form, it may still be true that within the range of capacity expansion regarded as reasonable in the short run, a straight-line function adequately describes the relationship between capital requirements and capacity. For these three reasons, the studies have emphasized marginal rather than average coefficients. It is conceivable that in a different context the reverse would be true. In that case the data problems would be multiplied, since in order to derive average coefficients it would be necessary to have information on the existing capital structure in the industry including the age distribution of equipment.

Form of Capacity Expansions

The decision to concentrate upon marginal capital coefficients does not define in a unique way measures relating capital requirements to capacity expansions. A different set of marginal coefficients applies to each of the methods by which capacity may be expanded in the plant or in the industry[5]. Capacity may be expanded by:

1. Building a completely new plant at a new location.
2. Building new and separate productive facilities at an existing location and utilizing the overhead facilities, e.g. general office building, laboratory, etc., of the existing plant.
3. Reproduction in large part of all of the processes in a plant in such a way as to tie in the new expansion with the existing equipment (the case of so-called scrambled facilities). At times such an expansion may utilize existing floor space but just as frequently new buildings are required for one or more of the processes.
4. The elimination of bottleneck areas in which case only a few key processes in the plant are affected. For example, in a copper smelter it may be feasible to expand capacity by adding an additional reverberatory furnace (or by lengthening one) without in any way affecting the ore handling, roasting, converting, or casting facilities.
5. The rehabilitation of idle plant (reopening of hitherto submarginal facilities). In some ways the problems introduced by this method are similar to those of method 6.
6. By conversion of existing facilities of another industry.

Methods 1, 2, and 3 above have certain elements in common. They involve expansion in all, or virtually all, production processes. Methods 1 and 2 involve essentially wholly new plants and even in the case of scrambled facilities the production process may be traced wholly in terms of the new equipment, although for administrative and other purposes the new is intermingled with the old. Thus in some sense the first three methods may be said to represent "balanced" expansions. The concept of a balanced expansion is admittedly flexible. In these studies it reflects the fact that the capacity in all processes in the plant are being expanded *pari passu* in order to achieve an "optimum" plant in the neighborhood

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[5] F. T. Moore, "The Sequence of Uses of Capital Coefficients," Bureau of Mines, Inter-Industry Analysis Branch Item 3, processed, April 7, 1952.

of the capacity expansion being considered. It implies, furthermore, that no process or group of processes is being expanded in such a way as to leave the plant with excess capacity in those processes after the capacity expansion. Whether or not the expansions represented by methods 1 through 3 were actually balanced in the above sense was determined, in the individual industry studies, by an analysis of engineers' reports, of engineering production flow diagrams, and by a compilation and study of the individual pieces of equipment which went into each expansion. Furthermore a comparison of individual coefficients for all plants in the sample frequently revealed coefficients which were out of line. A resurvey of the individual plant frequently indicated the reason for the atypical coefficient.

The elimination of bottleneck areas represents an unbalanced expansion. For a study of such expansion it is necessary to know a great deal about the capacity of individual processes in the plant. It is conceivable that in particular plants in particular industries the breaking of bottlenecks may add measurably to capacity with a small capital expenditure. It is harder to imagine that, in the industries considered, a complete industry could expand its capacity very much through the elimination of bottlenecks. A reader interested in making a strong case for this type of expansion might draw on some of our data in which the addition of a general office building or a washroom is said to add 10 to 20 per cent to capacity.

Methods 5 and 6 (rehabilitation and conversion) seem to represent still a third type of capacity expansion. In both of them the salvage of productive equipment is the important thing. Some equipment may be refurbished or converted; some just be replaced either because of deterioration or unsuitability. In some instances expenditures normally accounted as maintenance and repair are sufficient to recapture capacity. An example of this occurs in the pumping of water from abandoned mines, the first step in bringing them back into production. In any event the capital expenditures for rehabilitation and conversion are different from those of either balanced or unbalanced expansions; therefore these two methods are not covered in the current studies.

For better or worse the studies were limited to the balanced expansions. It is obvious that in any actual industry expansion all sorts of variation will occur. The first increment of capacity may be realized by the elimination of bottleneck areas, the next by the addition of scrambled facilities, the third by the building of new plant and/or the reactivation of idle plant, and so on. More usually capacity would be expanded by several of these methods simultaneously. In order to describe such a process adequately it would be necessary to have sets of capital coefficients for each of the different methods and to weight them so as to reflect the relative importance of one kind of expansion over another for given amounts of capacity increase, For each block or increment of capacity a set of capital coefficients representing a unique combination of the various expansion methods would be employed. The sequences of coefficients may be incorporated in dynamic interindustry models or used otherwise in individual industry studies. To obtain a proper sequence of coefficients, however, presupposes a knowledge of a number of factors which are outside the immediate scope of this study.

The emphasis upon the derivation of balanced capital coefficients is not as limiting a condition as might be supposed. From the set of balanced coefficients one or more sets of coefficients representing unbalanced expansions can be derived. The process is relatively straightforward. What is required is information about the processes in the plant for which there is excess capacity and about those which are working close to capacity. Then for any given size of capacity expansion, the balanced coefficients for the processes with excess capacity can be adjusted downward so as to require only those capital expenditures necessary to provide the increments to capacity over and above the existing excess capacity. It is evident that unbalanced expansions may be accomplished in a wide variety of ways; consequently there is no point in trying to derive a unique set of coefficients representing unbalanced expansions. The appropriate set of coefficients to be used will depend upon the degree of balance in the plant just prior to the expansion and on the extent to which future expansions build in additional imbalances. It would, of course, be valuable to have a catalog of the balance or imbalance found in productive facilities throughout all industry; but it would almost certainly be out of date as soon as it had been compiled. The set of balanced coefficients may be regarded as limiting values for coefficients representing unbalanced expansions since the latter may in many cases be derived from the former. Therefore the emphasis upon the derivation of sets of coefficients representing balanced expansions seems to be the best and more sensible method of procedure.

Inasmuch as the sample size in an industry study is frequently small, as much information as is possible should be salvaged. The most desirable situation is one in which all of the observations in the sample are of balanced plant expansions, but in many cases the majority of plant observations were of unbalanced expansions. At this point the compilation of the number and type of individual pieces of equipment utilized in the expansion became helpful. The plant observations were composed in terms of the processes, or aggregations of processes, which were necessary for productive operation. The product detail within each process was then compared for the balanced and the unbalanced expansions. Since the coefficients are derived for four-digit standard industrial classification codes for each process individually, the greatest possible use has been made of the data which are available. The product detail from the unbalanced expansion thus rounds out and serves as a check on the information contained in the balanced expansions.

Definition of Capacity

In the capital-to-capacity ratios it is equally important to be certain of the content and consistency of the definition of capacity so as to measure capital inputs accurately. The definition of capacity itself may determine the type of capital coefficients to be employed. It is usual to define the capacity of an industry in terms of some key process or fixed factor assuming that there are no supply limitations on other factors to that industry. In such a case, the process with the smallest capacity and the least flexibility sets the limits for the whole plant. After the smallest process has been pushed to its limit, additional capacity is still available in one or more of the other processes. This further suggests that if one unit were added to the smallest process (an unbalanced expansion), capacity can be further expanded.

The concept of a balanced expansion runs somewhat counter to this idea; it stresses the complementary character of capital goods. It might also be interpreted as meaning that expansions of capacity by means of unbalanced additions are of limited importance; as larger blocks of capacity are added complementarity becomes of greater importance since the lumpiness or indivisibility of capital goods requires the entrepreneur to look for the next larger lowest-common-denominator for all of the processes in the plant. This sounds paradoxical since a single set of capital-to-capacity ratios is identified with complete divisibility of capital equipment; however, it is entirely possible that each successive block of capacity increase would be achieved by a balanced expansion, but each block might be represented by a different set of capital coefficients. This means that if complementarity is complete, the isoquants are right angles; changing ratios among capital goods lead to an expansion path represented by a line with kinks in it, a kink occurring whenever the ratios change. E. H. Chamberlin has argued that changes in the aggregate amount of capital goods used (with consequent changes in specialization) are a source of economies of scale in addition to the economies resulting from lumpiness or indivisibilities[6]. This argument is consistent with that of the kinked expansion path. Assume that for capacity increases of up to 100 units, one set of coefficients is appropriate, and furthermore that perfect divisibility of capital goods applies; for capacity increases of 100 to 200 units a different set of coefficients may be appropriate while maintaining the assumption of perfect divisibility, and so on for successive blocks of expansion in capacity. Changes in the ratios in which capital goods are used may occur as the aggregate amount of them increases; yet within each block perfect divisibility may be assumed to hold true.

Capacity cannot be defined in terms of fixity of all factors employed in the industry. Some factors must be variable. For example under given conditions capacity may be limited by the available labor supply; however, a definition of capacity usually excludes such conditions. The question becomes one of deciding what factors are normally variable in the short run. The supply of all such variable factors is then usually assumed to be infinitely elastic at going prices. If there are supply limitations on a large number of the factors which the industry uses, the capacity of that industry cannot be evaluated independently but must be regarded as a function of the capacity and output in those industries which supply it. Such a chain of reasoning makes it impossible to define the set of capital coefficients which should be used for any given capacity increase.

The definition of capacity used in these studies includes several elements:

1. It assumes that there is an infinitely elastic supply of all variable factors.
2. It assumes that only present plant and equipment are available for use and that no changes in production techniques are made.
3. Measurement is in physical units rather than in value units; however, the problems of joint or common products and product mixes are handled individually from one industry to the next. In some industries the use of value terms to solve the product-mix

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[6] E. H. Chamberlin, "Proportionality, Divisibility, and Economies of Scale," *Quarterly Journal of Economics*, February 1948.

problem is avoided by establishing product conversion ratios or standard product units.

4. Normal industry practice is followed with regard to work hours, work week, and number of shifts. Each of these elements requires some elaboration, not only for a full understanding of these studies but also for the light which may be shed upon the general problem.

The definition of capacity not only has physical or technological but also time dimensions. The latter impresses itself upon us in at least two ways. In the first place, capacity through time is a function of the physical depreciation of the plant and equipment. Theoretically if the capacity of a plant at the beginning of a period is x, at the end of a period the capacity is x minus some quantity, as a result of depreciation in use. Strictly speaking, if capacity is expressed as a yearly figure, it may refer to the beginning of the year, the end of the year, or an average over the whole period. It is doubtful, however, that plant and equipment ever wear out in any simple fashion. It is just as logical to assume that maintenance expenditures (which are a flow item) preserve the capacity of a plant without any deterioration. That is the assumption which has been made here.

There is a second aspect to the time dimension. The capacity of a plant operating with 3 shifts, 24 hours a day, 5 days a week, is obviously different from that of a plant operating with 1 shift, 8 hours a day, 5 days a week (although the capacity of the former is not necessarily anything like three times that of the latter).[7] In the mining and metal industries an attempt was made to determine normal industry practice with regard to work hours, work days, and number of shifts. For example in the copper mining and milling industry normal practice means a 3-shift, 24-hour daily operation in the mill and 2 shifts in the mine with perhaps a third shift for repair operations. Since the data were drawn from plants built and operated during World War II as well as those built and operated in the last few years, the individual plant capacities sometimes reflected differences in shifts worked. To the best of our ability the observations were corrected for normal (peacetime) arrangements.

In one industry (zinc smelting) potential changes in production techniques raised special problems. Zinc smelting by the horizontal retort method is a batch process. Production is carried on in cycles of three operations: preparations of the furnace, smelting,

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[7] Samuel Weiss and S. L. Wolfbein, "A New Approach to Capacity Measurement," presented at the Annual Meeting of the American Statistical Association, mineographed, December 27, 2952.

and cleaning up. By a kind of doubling up of the operations the plant capacity may be changed; therefore in the derivation of the plant coefficients it was necessary to express all capacities in terms of a standard production cycle.

In most of the mining industries the product structure may be specified to avoid any complications introduced by joint or common products, and permit the use of a physical measure of capacity. The unit of measurement in these industries is a ton of ore. The introduction of values serves only to complicate the problem. While a rock ton of ore is a relatively homogeneous unit, the assay and composition of ores vary widely. Most copper ores contain some gold and silver; other ores are classified as copper-lead, lead-silver, lead-zinc, etc. In these ores the percentage of each type of metal is highly variable; therefore in the mining industries capacity was best expressed in terms of the tons of ore handled yearly. In the smelting and refining industries the problem was no more difficult. In copper smelting and refining, capacity is expressed in terms of tons of refined copper. In aluminum reduction the measure is tons of pig. The product mix was most serious in the rolling and drawing industries (aluminum, copper, other nonferrous) and in nonferrous foundries. In aluminum rolling and drawing a main distinction was made between rolled products and extruded products. One difficulty in measuring the capacity to produce extruded products, for example, lay in the fact that both hard and soft alloys are produced. Generally speaking a plant has a greater capacity if it concentrates upon the soft alloys than if it produces only the hard alloys. A hard alloy extrusion requires a greater pressure to force it through a die orifice than does a soft alloy; alternately, if pressure is held constant, production speed is less for a hard alloy. The same facts apply to rolled products.[8] For the specific plants in the sample the problem was solved by determing conversion ratios between hard and soft alloy products so that capacity could be expressed in terms of either one of them. It was determined that in the same working time three pounds of soft alloy tubing or one pound of hard alloy tubing could be produced. The conversion ratio was 1.857:1 for extruded shapes. By applying the conversion ratios the capacity (and the capital coefficients) can be expressed for either of the two products. If a single set of coefficients is to be derived reflecting mixtures of hard and soft alloys and of rolled

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[8] P. Crosson, G. Zec, F. Kelly, and S. Sonenblum, "Capital Coefficients for the Integrated Aluminum Industry," Bureau of Mines, Inter-Industry Analysis Branch Item 43, processed, November 25, 1953.

and extruded products, the appropriate coefficients for each of these can be weighted and then combined. In an interindustry model the weights will be determined by a survey of the consumers of aluminum rolled and drawn products to determine in what proportions they are using rolled or extruded products and hard or soft alloys.

In the other nonferrous rolling and drawing and extrusion industry and in the nonferrous foundry industry, the difficulties of deriving meaningful capital coefficients and capacities were compounded by the existence of different kinds of metals. However, it was felt that the densities of the various metals could furnish a key to the type of needed conversion factors. Experimentation seemed to indicate that the product of the total capital coefficient times the appropriate density tended to be the same for all metals. Table 1 will serve to illustrate this rather important point. If coefficients are computed for metal A, these can be converted into coefficients for metal B by multiplying by the ratio of the density of metal A to the density of metal B. Or alternatively the capacity of a given plant to produce metal B can be determined by multiplying the capacity to produce metal A by the ratio of the densities. In either case a basis seems to have been established for handling the calculation of capital coefficients and capacities. Actually, of course, there is a logical basis for using densities in this manner. We may link up the essential points by saying: capacity is a function of the speed of rolling or extrusion; speed is a function of the amount of pressure applied, the number of passes through the rolls, etc. and these latter factors are a function of the density of the metal. The relationship may also be expressed as a constant coefficient per unit volume of the metals.

TABLE 1

Relationship between Densities of Metals and Their Capital Coefficients

Product	*Total Coefficients*	*Density*	*Density × Coefficient*
Rolled products:			
Aluminum	$ 495	165	81,675
Copper	137	534	73,158
Extruded products:			
Aluminum	1,185	165	195,525
Copper	367	556	204,052
Magnesium	1,935	108	208,980

If capital coefficients for metal A can be converted to those for metal B by simply multiplying by the ratio of the densities, it is necessarily true that the same capital equipment is used in the production of each. Furthermore the capacity of the plant is interchangeable between the two metals (or between any combination of the two determined by the ratio of the densities). In the industries covered here, the interchangeability of capital equipment is reasonably well established. Nonferrous rolled, extruded, and cast products do use the same equipment. To shift from one metal to another involves essentially minor readjustments in production.

In all the industries in this study, methods were found for defining capacity without resort to value terms. Certainly the product structure in these industries is simpler than those found in most manufacturing industries. On the other hand, ingenuity in the use of conversion factors and standard product units may perhaps offer solutions to the measurement of capacity in certain other industries.

Economies of Scale

A vexing question which arose in these studies was whether the composite plant should be representative in scale as well as in other characteristics. If we work on the premise that the function relating capital and capacity is homogeneous of the first degree, there is no problem; the premise rules out the possibility of economies of scale. Two courses of action seem to be open:

1. To determine, by reference to the sample data available, the function relating capital cost to capacity. This will usually be done by determining the regression of (either) one upon the other. On the basis of some criteria, a representative size of plant is then chosen and capital coefficients are computed. The representative size of plant chosen may be one of the actual plants in the sample; however, even in this case the calculation of coefficients is not necessarily simple since other plants in the sample may have the more detailed cost breakdowns which are required. If a point on the regression line is chosen, the plant is a hypothetical one, and the cost breakdowns must still be determined from the actual plants in the sample.
2. To disregard the scale factor initially, i.e. to accept the above-mentioned premise, and to compute coefficients directly from the sample. At a later point in the analysis, the scale factor may be reintroduced and adjustments made by allowing unbalanced expansions, different sets of balanced coefficients, etc. for successive blocks of capacity.

These two approaches are not completely different; perhaps the difference is basically one of emphasis and timing. Good arguments can be adduced for each. The second approach has been followed in these studies. If a correlation is to be made between total capital cost and capacity, one naturally hesitates in the choice of dependent and independent variables since the classical least squares method assumes that *all* of the errors are in the dependent variable. Nothing is to be gained by choosing, as the dependent variable, the measure which a priori seems to have the most error. Under these circumstances the eclectic in statistics might retreat to orthogonal or weighted regressions; however, at that point the matter ceases to have interest for the analyst, who has limited time and money.

The studies of economies of scale made for these mineral and allied industries are not conclusive but indicate something of the results which are to be expected. An analysis was made of alumina, aluminum reduction, aluminum rolling and drawing, and cement. The results for all except aluminum drawing indicate the existence of economies of scale; however, the results do not test out significantly different from the hypothesis of constant returns to scale. The studies were made by considering the function $E = aC^b$, where E is the total capital cost of the plant, C is the capacity in physical terms, and a and b are constants. The relationship between total capital cost and capacity may be somewhat clearer if the function is considered in form $\log E = \log a + b \log C$. The existence of economies of scale associated with the arrangement of capital goods is evidenced by values of b less than one. If, for example, $b = 0.9$, total capital cost increases only as the 0.9 power of capacity. A value for b less than 1 indicates that the envelope cost curve falls as scale of plant is increased. A value of $b = 1$ indicates constant returns.

In these studies the values of b which were secured vary from 0.77 to over 1.0. Table 2 shows the values of b for each of the industries and for the two conditions (1) when E is defined as total

TABLE 2

Scale Factors for Selected Mineral Industries

Industry	*Total Plant*	*Equipment*
Alumina	0.95	0.93
Aluminum reduction	0.93	0.95
Aluminum rolling	0.88	0.80
Aluminum drawing	1.00	0.92
Cement	0.77	1.06

plant cost, and (2) when E is defined as total equipment cost. A t-test applied to each of the values less than 1 indicated that none were significantly different from 1, i.e. testing against the hypothesis of constant returns. In addition to the above tests the formula was applied to specific pieces of equipment (as represented by the four-digit SIC code) in these industries. The values of b which were secured ranged from 0.24 to 1.13 in the alumina industry; 0.381 to 1.247 in aluminum reduction; and 0.416 to 7.070 for aluminum rolling and drawing. These results are regarded as preliminary only; several problems of measurement and classification require further attention in this area; however, the ranges in the values of b indicates substantial variations in economies of scale by process or department in the plant. It further indicates some of the difficulty of balancing the process capacities and of achieving an optimum plant for a given range of output.

Derivation of Capital Coefficients[9,10]

More or less standarized procedures were utilized in the derivation of capital coefficients. The basic sources of data were from government records of several kinds.

1. Records of plants built by the Defense Plant Corporation during World War II (the so-called Plancors). The Appendix A in the Plancor records lists each piece of equipment which was installed in the plant together with a description of expenditures on construction, land improvements, engineering and other fees, and construction and installation labor.
2. The applications for certificates of necessity for accelerated amortization during World War II and during the current mobilization period.
3. The records on direct government loans and/or purchase agreements. The government records furnished the most detailed information on expenditures.

In addition a number of technical publications were used to determine technical characteristics of equipment, equipment capacities, production methods, and the like. The most useful of these publications were: *Peele's Mining Engineers Handbook; Handbook of Nonferrous Metallurgy*, D. M. Lidell, editor; J. L. Bray, *Non-*

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[9] Sidney Sonenblum, "Derivation of Capital Coefficients," Bureau of Mines, Inter-Industry Analysis Branch Item 14, processed, October 20, 1952.

[10] G. Zec, "Use of Asset Property Records in the Derivation of Capital Coefficients," Bureau of Mines, Inter-Industry Analysis Branch Item 14A, processed, February 10, 1953.

ferrous Production Metallurgy; A. F. Taggart, *Handbook of Mineral Dressing; Denver Equipment Index*, the Denver Equipment Company; and various issues of the Bureau of Mines technical publications including bulletins, reports of investigation, and information circulars.

The government records used were a mixture of actual (*ex post*) and estimated (*ex ante*) expenditures. The Plancors gave actual expenditures on equipment and construction; individual invoices were available when necessary. Many of the applications for certificates of necessity from World War II contained data on the actual expenditures as well; but the certificates originating after 1950 frequently contained only the firm's estimates of costs. Both kinds of data were included. No particular tests were made to determine whether the estimated costs were close to the actual costs incurred. However, since the Plancors were the most detailed records, they were relied upon to a much greater extent than the certificates of necessity. Therefore the coefficients contain an unknown (but probably small) bias from the use of the estimated costs.

Some tests were conducted to determine whether the estimates of the expansion in capacity secured by the capital expenditures method were confirmed by later records of production. Output series (by months) for a number of new plants were secured and compared with the estimates of capacity from the government records. The results of the comparisons tended to bear out the conclusion that the engineering estimates were accurate.

The initial step in processing the data consisted of coding each item according to type of expenditure. The expenditure categories were: equipment, construction materials, equipment installation labor, construction labor, land improvement, and miscellaneous (engineering and architectural fees, etc.). Each item of equipment was further classified according to the four-digit standard industrial classification industry from which it originates; for example a ball mill was classified in SIC 3531 (construction, mining, and similar machinery). Construction materials, on the other hand, were not classified according to SIC industries of origin (e.g. cement, lumber, etc,) but were lumped in a single category. This procedure conforms to the requirements of an interindustry model in which construction is handled exogenously. At some future time these construction materials may also be allocated to four-digit SIC industries.

Since the plants in the sample frequently were built in different years, the necessary next step was to deflate the data to some common base (usually 1947 and/or a current year). Price deflation was performed on each four-digit SIC industry separately, using price indexes specifically provided for this project by the Bureau of Labor Statistics. At least a part of the interplant variation in coefficients may be ascribed to the fact that these price indexes all too frequently were deficient. Following the price deflation, an estimate was made of the expansion in capacity (in keeping with the factors previously mentioned), and plant coefficients were then derived by dividing the value of the capital inputs from each supplying industry of each expenditure category by the capacity increase of a plant.

The derivation of these plant coefficients was not so simple as has been recounted above. A number of very perplexing questions intruded upon the analysis. Plants reported their expenditures in various degrees of aggregation and with various reporting practices. Some reported equipment cost and installation labor as one item; others reported them separately. The problem of equipment complexes or major facilities were particularly difficult. In our lexicon an equipment complex represents a group of items used as a single unit of production, the parts of which may be purchased individually or as a parcel. A conveyor system is illustrative of such an equipment complex; it may be composed of the conveyor belt, frame and housing, a motor, and installation labor. At times such an expenditure was listed as a single item, and at other times each of the component parts was listed separately. Allocation of such expenditures among individual SIC's was accomplished by referring to technical publications and by prototyping, i.e. by applying to the total expenditure for the equipment complex the percentage breakdown of expenditures on components which existed for another plant in the sample. In the case of Plancors it was possible to go behind the Appendix A's to the asset property records, which contain all the original invoices and other detailed information on the construction of the plant. To use the asset property records completely involved a prodigious amount of work since they contain information down to the kind of nuts and bolts which went into the plant. Although they were not used uniformly in all of the industry studies, they were resorted to for the most difficult cases.

The final and in many ways the most difficult step was to derive a single set of capital coefficients for the industry by averaging the individual plant coefficients. Frequently there was substantial interplant variation for individual coefficients in the set so that the averaging procedure could not be done mechanically. It was necessary to try to reduce or explain the variation in terms of differences in geographical location, existence of excess capacity in some parts of the plant, the size or scale of the expansion, differences in technological processes, differences in the classification of expenditures, or substitutions among capital goods, e.g. the use of trucks instead of railroads. The analyst was called upon to exercise a great deal of judgment. A product detail table was compiled showing the specific pieces of equipment included in each four-digit SIC for each plant. A comparison of the plants utilizing this product detail table occasionally revealed differences in technology, substitutions, degrees of imbalance, etc. At times the product detail table was complemented by a complete process analysis of the industry. The major processing stages in the plant were determined and individual pieces of equipment were allocated to them. A comparison of the coefficients, stage by stage, among the plants was then made. The purpose behind each of these methods was to reduce the amount of unexplained variation among coefficients for different plants.

It was usually impossible to reduce to zero the interplant variation in coefficients although substantial reductions could usually be achieved. In the final analysis it became necessary to take an average of the plant coefficients for each SIC industry. In the usual case the sample was small so that the median was the average most used. In this way a single set of capital coefficients for a composite plant in the industry was derived. When a separate set of coefficients had been derived for each of several different production processes, e.g. open pit and underground mines, these sets were then combined into a final single set of coefficients by a weighting procedure. The weights adopted initially were the percentages of output currently attributed to each of the production methods; however, as was pointed out earlier, any of several different weighting systems could easily be employed.

Variability in Capital Coefficients

It is too much to expect that interplant variation in capital coefficients can be precisely measured in terms of the parameters causing such variation. As has been mentioned above, interplant variation was reduced but never entirely explained. Some of the factors inducing variation are obvious; the geographical location of the plant affects its expenditures for construction, land improvements, and the like. An illustrative case occurs in primary aluminum. One plant was built near the Canadian line, in rough terrain where expenditures on grading, leveling, road-building, etc. were substantial; a second plant was built in the South where these expenditures were nominal.

Plant practice also differs among firms. Some tend to build in larger safety factors than others; some choose to provide their own powerhouses for at least a portion of the electric power required; some choose (or are forced) to provide more of the amenities for the plant labor force. The list can be easily extended.

On a somewhat different level is the effect of entrepreneurs' expectations as to future demand. During the war it was obvious that some of the aluminum capacity would be uneconomic to operate in the postwar period even under the most favorable demand conditions, while others of the new plants looked promising. The expenditures on these two types of plant differed as to permanence of construction, machine complexes installed, etc. Since the government absorbed the cost of the facility, and since the capacity was to be brought in as rapidly as possible, some expenditures were made which would not have been made by a private firm in peacetime conditions. Some of these expenditures were identified from the records, but it is reasonable to suppose that others of like kind were undetected.

Table 3 illustrates the variability in plant coefficients encountered in the aluminum industry. On the whole the interplant vari-

TABLE 3

Interplant Variability of Capital Coefficients in the Aluminum Industry

Plant and Processes	*Capital Coefficient (1942 dollars per ton)*
Alumina:	
Plant C	50.55
Plant D	48.04
Aluminum reduction:	
Prebaked carbon:	
Plant E	237.35
Plant F	402.08
Plant G	233.50
Plant H	402.81
Soderberg:	
Plant I	232.12
Plant J	285.49
Plant K	286.82
Aluminum rolled products:	
Plant L	353.42
Plant M	396.61
Plant N	351.26
Plant O	213.10

ation is fairly small, but the samples are also small because the original samples were carefully screened so as to obtain plants which were homogeneous in as many respects as possible.

2. *The Individual Industry Studies*

A separate report was prepared for each of the industries (and/or products within the industry) concerned with the mining, milling, smelting, refining, or rolling and drawing of metals and nonmetallic minerals. Some of the most interesting of the methodological problems and results arising from these studies will be summarized below; however, since some problems recurred in more than one industry, no attempt will be made to discuss all of the industries covered.

For each industry and/or product a detailed table similar to Table 4 was prepared. These are available in the individual industry reports prepared by the Office of Chief Economist, Bureau of Mines. Table 5 is simply a list of the total capital coefficients for all industries and products.

Copper Mining and Milling[11]

One of the most complete studies was made of the copper mining and milling industry. In the final sample, information on seventeen different plant expansions was used. The sample was a heterogeneous one; it included relatively large plants as well as relatively small ones, and open pit mines as well as underground mines in which a variety of mining methods were employed. Geographically the plants were scattered from Vermont to California; there were variations in the richness of the ore handled and the size and geologic characteristics of the deposit.

The majority of the observations represented expansions of existing facilities; there were no completely new plants but there were several for which the expansion was several times larger than the existing facility, so that they could be considered legitimately as balanced expansions. In order to utilize fully all of the observations, a process analysis was mandatory. Ten process areas were established to facilitate the allocation of expenditures: (1) mining; (2) compressor operations for generating compressed air, primarily for mining operations; (3) crushing operations; (4) concentrating operations including fine grinding and gravity and flotation equip-

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[11] Sidney Sonenblum, "A Report on Capital Purchases by the Copper Mining and Milling Industry," Bureau of Mines, Inter-Industry Analysis Branch Item 21, processed, February 20. 1953.

TABLE 4

Illustrative Detailed Table of Capital Coefficients for the Copper Mining and Milling Industry

	Capital Coefficients[a]		
Industrial Sources of Capital Inputs	*SIC Industry of Origin*	*1947 Dollars*	*1950 Dollars*
Equipment total		$2.768	$3.307
Saw mills and planing mills	2421[b]	0.005	0.006
Office furniture	2520[c]	0.007	0.008
Industrial rubber	3099	0.004	0.004
Steel works and rolling mills	3312	0.028	0.037
Iron and steel forgings	3391	0.001	0.001
Welded and heavy riveted pipe	3393[d]	0.044	0.058
Edge tools	3422	0.001	0.001
Hand tools	3423	0.004	0.005
Oil burners	3432	0.002	0.002
Heating apparatus	3439	0.008	0.009
Boiler shop products	3443	0.087	0.115
Sheet metal works	3444	0.001	0.001
Lighting fixtures	3471	0.002	0.002
Wire work	3489	0.006	0.008
Screw machine products	3494	0.001	0.001
Construction and mining machinery	3531	1.461	1.780
Machine tools	3541	0.017	0.022
Metal work machinery	3542	0.008	0.010
Machine tool accessories	3543	0.005	0.006
Woodworking machinery	3553	0.004	0.004
Special industry machinery	3559	0.003	0.004
Pumps and compressors	3561	0.183	0.212
Conveyors and conveying equipment	3563	0.104	0.126
Blowers and ventilating fans	3564	0.037	0.052
Mechanical power transmission equipment	3566	0.015	0.018
Industrial furnaces	3567	0.005	0.006
Computing machines and cash registers	3571	0.005	0.006
Typewriters	3572	0.001	0.001
Scales and balances	3576	0.015	0.017
Office and store machines	3579	0.001	0.002
Air conditioning units	3585	0.009	0.010
Measuring and dispensing pumps	3586	0.005	0.007
Valves and fittings	3591	0.005	0.006
Wiring devices	3611[e]	0.064	0.052
Measuring and recording instruments	3613	0.002	0.002
Motors and generators	3614	0.069	0.078
Transformers	3615	0.029	0.031
Switchgear and switchboard apparatus	3616	0.042	0.053
Electric welding apparatus	3617	0.006	0.006
Electrical equipment for industrial use	3619	0.001	0.002

(continued on next page)

TABLE 4 (continued)

Industrial Sources of Capital Inputs	*SIC Industry of Origin*	*Capital Coefficients*[a] *1947 Dollars*	*1950 Dollars*
Equipment total (continued)		$2.768	$3.307
Insulated wire and cable	3631	0.082	0.069
Radios and radio equipment	3661	0.002	0.002
Communication equipment	3669	0.015	0.018
Trucks and motor vehicles	3717[f]	0.271	0.325
Locomotives and parts	3741	0.086	0.106
Transportation equipment n.e.c.	3799	0.002	0.002
Laboratory and scientific instruments	3811	0.010	0.011
Measuring and controlling instruments	3821	0.001	0.001
Construction materials	Construction materials industries	0.787	0.902
Labor total		2.868	3.464
Equipment installation labor	Labor industry	0.389	0.470
Construction labor	Labor industry	0.804	0.971
Land improvement	Labor industry	1.207	1.458
Miscellaneous	Labor industry	0.468	0.566
Total plant		$6.423	$7.673

[a] Dollar value of capital inputs required per ton of increase in annual ore capacity.

[b] A detail listing of the products included in each of the Standard Industrial Classification industries was made before the final listing.

[c] SIC 2520 includes SIC 2521 (wood office furniture) and SIC 2522 (metal office furniture).

[d] SIC 3393 includes, in our data, SIC 3592 (fabricated pipe and fittings).

[e] All electric equipment which could not be precisely allocated to a four-digit SIC industry was included in SIC 3611.

[f] The SIC Manual of 1945 has no SIC 3717 industry. However, changes in the manual are expected so that SIC 3717 will include trucks and cars. In our data, SIC 3717 includes 3711, 3712, 3714.

n.e.c. = not elsewhere classified.

Source: S. Sonenblum, "A Report on Capital Purchases by the Copper Mining and Milling Industry," Bureau of Mines, Inter-Industry Analysis Branch Item 21, processed; February 20, 1953.

ment; (5) a general works area, including machine shops, warehouses, etc.; (6) a general administrative and laboratory area; (7) a plant utilities area including electric power distribution, water supply, etc.; (8) transportation; (9) development operations including the stripping of overburden and digging shafts and tunnels; and (10) housing operations. Each of the capital expenditures was allocated to one of the ten areas of operations and was further classified according to the type of expenditure, e.g. equipment, con-

TABLE 5

Total Capital Coefficients for the Mineral and Metal Industries

Industry or Product	*Capacity Unit*	*Capital Coefficient (1947 dollars per unit annual capacity)*
Copper mining and milling	ore ton	$ 6.42
Open pit operations	ore ton	6.67
Underground operations	ore ton	6.02
Bauxite mining	ore ton	2.81
Alumina	ton	69.33
Aluminum reduction	ton of pig	427.17
Aluminum rolling and drawing	ton	667.92
Extruded products		1,185.08
Rolled products		495.32
Integrated aluminum industry (bauxite through rolled and drawn products)	ton of rolled and drawn products	1,223.10
Copper smelting and refining	ton of refined copper	187.35
Smelting		94.93
Refining		92.42
Copper and brass rolling and drawing	ton of rolled and drawn products	173.46
Rolled products	ton	136.51
Extruded products	ton	56.49
Pipe and tube	ton	363.24
Zinc smelting and refining		
Horizontal retort	ton of slab	50.23
Electrolytic	ton of slab	134.74
Vertical retort	ton of slab	103.37
Electrothermic	ton of slab	90.76
Magnesium refining	ton of metal	
Electrolytic process		1,695.21
Ferrosilicon process		1,562.32
Other mining and milling	ore ton	7.25
Zinc ores	ore ton	6.05
Lead-zinc ores	ore ton	6.80
Lode gold ores	ore ton	7.65
Manganese ores	ore ton	9.15
Tungsten ores	ore ton	6.88
Ferro-alloy ores	ore ton	8.27
Titanium ores	ore ton	7.72
Nickel smelting and refining	ton of refined metal	1,549.04
Electrolytic tin	ton of refined metal	246.64
Electrolytic manganese	ton of refined metal	162.05
Nonferrous rolling n.e.c.	ton of rolled products	156.52
Nonferrous extruded and drawn products n.e.c.	ton of extruded and drawn products	360.13
Iron ore mining	ore ton	13.74
Cement	barrel per year	3.72
Bituminous coal	ton	3.93

(continued on next page)

TABLE 5 (continued)

Industry or Product	*Capacity Unit*	*Capital Coefficient (1947 dollars per unit annual capacity)*
Nonferrous foundries	1000 lb.	
Sand castings (1947 product mix)		$ 294.90
Aluminum die castings		260.01
Magnesium permanent mold castings		117.59
Stone, clay products		
Bentonite	ton	3.65
Crushed and broken limestone	ton	1.03
Rock salt	ton	1.06
Potash, soda, borate minerals	ton	9.65
Fluorspar	ton	6.92
Sand and gravel	ton	0.32
Phosphate rock	ton	1.63
Clay refractories	ton of 9 in. equivalent brick per month	1.23

n.e.c. = not elsewhere classified.

struction material, installation labor, etc. An area of operations was taken as the basic unit for analysis. For each plant in the sample capital coefficients were computed for each four-digit SIC industry within each of the ten areas. In the derivation of a single set of industry coefficients representing a composite plant, comparisons were made across the board for each SIC industry within each area of operation. Only by using a process analysis was the heterogeneity of the sample data reducible to workable terms.

In order to increase the homogeneity of the sample data, stratification was undertaken almost immediately. The most obvious distinction was between the open pit mines and the underground mines. Capital coefficients were computed for both types. From our sample it was determined that the total plant coefficient for open pit mines was 11 per cent larger than for underground, but that is not the extent of the differences. The composition of the expenditures is also quite different. A part of the differences in capital expenditures is obscured by the grossness of the four-digit SIC code; one illustration will suffice to illustrate this. SIC 3531 (construction and mining machinery) is the largest single supplier of equipment, but the specific equipment furnished is different for the two types of mines. Open pit mines purchase relatively more crushing and grinding equipment whereas the underground mines purchase relatively more concentrating equipment.

In these attempts to understand the sources of the coefficient variability the original sample was stratified according to eight different characteristics: (1) open pit versus underground; (2) plants with high grade ores versus plants with low grade ores; (3) World War II versus recent-year expansions; (4) long-lived versus short-lived reserves: (5) large scale versus small scale operations; (6) plants with a long construction period versus plants with a short one; (7) one-shift versus three-shift operations; and (8) plants with new equipment versus plants with extensive used equipment. Had the sample been larger it would have been interesting to cross-classify the data according to several of these criteria and to run analyses of variance on them. Instead each of the eight comparisons was made individually; the results of several of the comparisons revealed some of the sources of interplant variation in coefficients, but the differences found in the comparisons could not be tested for significance by any of the usual statistical tests because the variation in the coefficients is a function of all of these factors operating simultaneously. If a larger sample could be compiled, sample pairs which differ only as to a single characteristic could be selected and tested.

Bauxite Mining[12]

The sample in bauxite mining consisted of only two plants; one was an addition to an existing domestic plant during World War II and the other a plant built recently outside of the United States. The records showed nine separate applications for accelerated amortization for the first plant, each of which represented an unbalanced expansion in some area of the plant. Furthermore the capacity increases associated with these individual expansions were not always stated unambigously, so that the total increase in capacity associated with the complete expansion of the plant was difficult to measure. The analyst had to determine whether the individual capacity figures mentioned were significant economically. In the final analysis the total plant expansion was considered as a unit and, by reference to technical material, an evaluation was made of the degree of balance in the expansion. In order to make the two observations comparable, expenditures for port facilities, a railroad, and gondola cars were eliminated from the second plant. In view of the paucity of the data and of the numerous adjustments which had

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[12] Crosson, Zec, Kelly, and Sonenblum, *op. cit.*

to be made, the total plant coefficients are very close ($2.83 and $2.75), but the favorable results achieved here are attributable in large part to the simplicity of the product, the standardization of production methods in the industry, i.e. primarily by open pit operations, and the relatively few processes involved.

Alumina[13]

The study of the alumina industry was complicated by fewness of observations and multiple production methods. Alumina may be produced by straight, combination, or modified Bayer processes. Information was available on two combination Bayer plants, both of which were complete new plants constructed during World War II, and on three straight Bayer plants. Although something might have been gained by a comparison of the two production methods, the straight Bayer plants were excluded from the analysis because of the inadequacies in reporting and because they represented unbalanced expansions. The two plants which were finally used were similar in many respects; the total plant coefficients were $50.55 and $48.03 (1942 dollars) per ton of alumina capacity. Both were completely new plants utilizing the combination Bayer process. When an analysis was made of individual capital expenditures, however, a number of differences appeared. Those differences were traced to several factors: geographical location, the chemical structure of the ore processed, and differences in construction practices. One plant was in a remote location and could use natural ventilation whereas the other required capital expenditures for an exhaust and ventilating system; one required special equipment to blend domestic and imported ores whereas the other processed only domestic ores; one purchased separately the components for rotary kilns, coolers, thickeners, etc. whereas the other purchased these items in a unit. One may ask whether such variations in capital expenditures should, for an industry analysis, be regarded as permanent factors to be reckoned with or as only aberrational. Similar quesrions arise in any study of investment behavior of the plant, firm, or industry. They cannot be brushed off as of little importance.

Aluminum Reduction[14]

In aluminum reduction, observations were available on four plants using the prebaked carbon process and on three plants using the

[13] *Ibid.*
[14] *Ibid.*

Soderberg process. The sample of seven plants was regarded as excellent, for all of the plants were completely new. In this case it was felt that a straightforward comparison of the expenditure items could be made for each of the two processes. Among the problems that could be investigated fruitfully was the existence of economies of scale. The plant coefficients showed that, in general, as the scale of the plant increased the total capital coefficients, i.e. cost per unit of capacity, decreased. Before this tendency became apparent it was necessary to make a number of adjustments in the data. In the first place the prebaked carbon plants frequently tend to build capacity for the production of carbon anodes in excess of their own needs; the excess production is sold to other plants, which in turn have a smaller capacity in this area than they actually require. No attempt was made to determine the motivation or the occasion for either an overbuilding or underbuilding of carbon-baking facilities; but an attempt was made to correct it so as to show only that capacity which was actually needed to support the plant's operations. Furthermore some of the aluminum plants have their own power-generating facilities whereas others purchase their power. If a plant built excess capacity in the carbon-baking facility and had its own power-generating facilities, there also were expenditures for cooperating facilities, e.g. utilities, etc., to tie together the whole operation.

There were indications that operating costs for a Soderberg plant are somewhat lower than for a prebaked carbon plant but that the initial capital costs for the former are relatively larger. This posed a further question for the investigator: What are the determinants of the choice of production method under these circumstances? If the problems of choice involved in building carbon-baking capacity and electric power facilities are added to the choice to be made as to production methods, some paths for future inquiry into investment behavior in the aluminum industry are immediately indicated. They are not paths which we attempted to travel in computing capital coefficients for the industry.

Aluminum Rolling and Drawing[15]

Two sets of capital coefficients were computed for this industry, one for rolled products (plate, sheet, and strip) and the second for extruded products (shapes, rods, tubes). For any given expansion in the industry each set must be weighted by the percentage of the new capacity required for the specific product group.

[15] *Ibid.*

Of the plants in the sample five were new plants while the other three were large balanced additions; all eight of the expansions took place in the early years of World War II. By 1944 when these plants were in operation their capacity represented almost two-fifths of the total capacity for rolling and drawing of aluminum products. In addition, the sample plants embodied the newest developments in production techniques, e.g. the rolling mills were of the continous strip type.

One of the more interesting aspects of the measurement of capacity in this industry has been mentioned earlier in this paper. Since products with different alloy compositions may be produced, the distribution of products among soft and hard alloys is a significant determinant of the capacity of the plant. In order to express capacity in terms of a standard unit of measurement, conversion ratios between hard and soft alloy products were determined from the plant data. This permitted the expression of capacity in units of either one or the other of the two alloy types. Another determinant of rolling mill capacity is the lot size. If the rolls may be set once for a given alloy composition, gauge, etc., and then run steadily for two weeks, the volume of output produced is substantially larger than if the rolls have to be reset several times for different alloys and gauges. Effective production scheduling may increase the capacity of a plant by lumping orders so that the plant may operate for longer sustained runs. Thus the capacity of a plant is, at least in part, dependent upon management decision and the character of demand for products. In this study the coefficients were based upon capacity to produce hard alloys, and the lot size was assumed to be the same as in the early years of operation of the plant, i.e. 1943-1945).

Copper Rolling and Drawing[16]

The problems encountered in the aluminum rolling and drawing industry were repeated in this industry. The solutions as well were approximately the same. Capital coefficients were computed for three different product groups; flat rolled products; extruded rods, bars, and shapes; and pipes and tubes. The coefficients were derived from a total of eight plant observations; five of the observations were on rolling facilities, two on extruded products, and one on pipes and tubes. The product-mix problem recurred here as

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[16] G. Zec, "Capital Coefficients for the Copper Rolling and Drawing Industry," Bureau of Mines, Inter-Industry Analysis Branch Item 44, processed, December 16, 1953.

before; the products range from the soft or "yellow" brasses, e.g. 70–30 copper-zinc composition, to the hard or "red" brasses and bronzes, which concentrate in the range 85–90 per cent copper. Capacity was expressed in terms of the yellow brasses, which constitute the largest percentage of output of the brass mill industry.

Copper Smelting and Refining[17]

Capital coefficients for copper smelting and refining were computed from five observations: two new plants and three additions. Two of the observations were on a smelting operation alone; one was on a combined process of smelting and refining and the other two on a leaching operation and a hydrometallurgical process respectively. The sample was both small and heterogeneous. The largest volume of copper output is smelted in reverberatory furnaces and refined electrolytically. The capital coefficients are representative of these methods. The only substantial segment of the industry which was excluded was the capacity for smelting and fire refining of northern Michigan ores. Leaching and hydrometallurgical processes are limited to a few scattered firms in the industry.

Zinc Smelting and Refining[18]

Slab zinc is produced by a variety of methods; the ones noted are electrolytic, electrothermic, vertical retort, and horizontal retort. The first three methods are essentially continuous operations whereas the last is a batch operation. In addition, as a valuable by-product of the smelting and refining of zinc ores, sulfuric acid may be recovered by modification of the equipment and by addition of special facilities. For example in the horizontal retort process Ropp kilns may be used to roast the ores. In this case sulfuric acid is not recovered; or a different type of furnace may be used which does permit the recovery of sulfuric acid. Here again is a problem in motivation and choice. Under what conditions will the firm invest in facilities for the recovery of the by-product? A fur-

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[17] E. Colleran, "Capital Coefficients for the Copper Smelting and Refining Industry," Bureau of Mines, Inter-Industry Analysis Branch Item 50, processed, June 30, 1954.

[18] A. Fothergill, "Capital Coefficients for the Zinc Smelting and Refining Industry," Bureau of Mines, Inter-Industry Analysis Branch Item 49, processed, February 26, 1954. F. Westfield, "Capital Coefficients for the Horizontal Retort Process of the Zinc Smelting and Refining Industry," Bureau of Mines, Inter-Industry Analysis Branch Item 38, processed, October 7, 1955.

ther problem in the imputation of costs also arises. Should any part of the cost of the roaster be imputed to sulfuric acid or should all of the cost be imputed to the primary product, zinc? In these studies all such costs were allocated to the primary product, but it is easy to imagine circumstances in studies of investment behavior which would require a different solution.

Capital coefficients are presented for each of the four methods of production. Facilities for the production of sulfuric acid are specifically excluded. All of the capital coefficients refer to the cost per unit of capacity for producing slab zinc. This product designation would seem to be homogeneous; however, there are a number of grades of zinc which differ in purity, ranging from Special High Grade to Prime Western. The horizontal retort process is essentially set up to produce Prime Western, the lowest in purity but also the grade most widely used. Higher grades may be produced in a horizontal retort plant by successive redistillation, but the price paid is a lower capacity for the plant. The other three methods are better equipped to produce the higher grades of slab zinc. Consequently the differences in the capital coefficients for the four production methods reflect a difference in the value of product since the higher grades command a premium in price over Prime Western. Other differences in the capital coefficients are attributable to variations in the kind of ore processed, e.g. sulphide ore, willemite, franklinite, etc. When faced with such difficulties, are we still to assume that, for purposes of a capital coefficients study, there is actually *a* zinc industry? Or are there *several* zinc industries? Our solution was to compute separate sets of coefficients and to submit a tentative set of industry coefficients based upon the relative importance of the production methods utilized in the industry.

Magnesium[19]

Capital coefficients are presented for magnesium production by the electrolytic process and by the ferrosilicon process. The two processes stand in a rather peculiar relationship to each other. Total unit costs for an electrolytic plant are lower than for a ferrosilicon plant so that under normal market conditions the ferrosilicon plants would very quickly be shut down; however, the ferrosilicon process consumes much less electric power and is also more eco-

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[19] F. J. Kelly, "Capital Coefficients for the Magnesium Industry," Bureau of Mines, Inter-Industry Analysis Branch Item 37, processed, October 15, 1953.

nomical in the use of certain critical materials, both of which are likely to be in short supply in a mobilization or war period. The ferrosilicon plants are basically war babies and are uneconomical to operate in peacetime. One may conjecture as to the form which a capacity increase will take in the industry. If demand rises slowly through time, it is probable that the new capacity will be in electrolytic plants; but if there is a sudden surge in demand, such as is associated with war conditions, an expansion will almost certainly concentrate upon the ferrosilicon process. Under such circumstances studies of investment behavior and capital coefficients in the industry must wait upon the formulation of hypotheses about these other determining factors.

The electrolytic process is itself not homogeneous since three different raw materials (seawater, brine, and dolomite) may be used to produce magnesium metal. To pin-point the areas of similarity and difference five processes in the plant were distinguished: (1) magnesium chloride facilities (including chlorine-producing equipment); (2) magnesium metal production; (3) alloying operations; (4) power facilities; and (5) general works facilities. Capital coefficients were then computed for each of the four-digit SIC industries in each process area and a final set of coefficients for the whole plant was derived.

Other Nonferrous Minerals[20]

In addition to the nonferrous metals which have been discussed above, there are a large number of others which, because of lack of data or scattered data, could not be studied individually. In mining and milling there was a lack of information on lead ores, zinc ores, lead-zinc ores, and on a number of minor metals such as silver, manganese, molybdenum, tungsten, nickel, chromium, mercury, titanium, etc. In the smelting and refining stage of production most of these metals are lumped into a single industry called primary smelting and refining of nonferrous metals, n.e.c. (SIC 3339); and in the final stage of semifabrication they are included in the single industry, rolling, drawing, and alloying of nonferrous metals, n.e.c. (SIC

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[20] E. Colleran and A. Fothergill, "Capital Coefficients for the Nonferrous Metal Smelting and Refining Industry, n.e.c.," Bureau of Mines, Inter-Industry Analysis Branch Item 46, in preparation. P. Crosson, "Capital Coefficients for the Nonferrous Metal Mining and Milling Industry, n.e.c.," Bureau of Mines, Inter-Industry Analysis Branch Item 42, processed, January 28, 1954. G. Zec, "Capital Coefficients for the Rolling and Drawing of Nonferrous Metals, n.e.c. Industry," Bureau of Mines, Inter-Industry Analysis Branch Item 45, processed, January 6, 1954.

3359). It is obvious that these are not industries in any economic or technological sense but are the catch-alls of a classification system. It is impossible to derive sensible sets of capital coefficients for such "industries." On an individual product basis, however, the coefficients are meaningful.

Capital coefficients for the mining and milling of these ores have been derived by prototyping from the copper mining coefficients and by making specific adjustments in certain of the items. It is true that mining operations by their very nature tend to be standardized. The basic operation is the removal of ore from veins and beds and the transportation of it to a mill. The primary factors determining the capital equipment necessary are the depth and extent of the deposit, the geological characteristics of the occurrence of the mineral in the rock, the hardness of the surrounding rock formations, etc. A study of these factors for each of the specific metals led us to believe that with some specific exceptions, and with some modifications, the copper-mining coefficients could be used as prototypes.

Milling operations (the first step in the separation of the mineral from the rock) are not so standardized among these metals and the prototyping applies much more narrowly. For example mercury ores can be roasted directly and the mercury collected as vapor and then distilled; titanium ores are concentrated primarily by magnetic and electrostatic methods, both of which are different from copper-milling methods. The list of exceptions is not one to inspire confidence in the prototype coefficients. In smelting and refining it was possible to compute capital coefficients for three metals, nickel, tin, and manganese.[21] No attempt has been made to establish industry coefficients for the smelting and refining of these ores. On a purely formal basis it would be possible to compute capital coefficients for a number of other metals and to combine these sets by some arbitrary weighting system, but a set of coefficients derived in this way would have little meaning since the proportions represented by each of the metals would be frozen.

An estimate of the capital coefficients for the rolling and drawing of these heterogeneous nonferrous metals was made by generalizing from the copper and aluminum rolling and drawing coefficients. The validity of the estimate hinges on one key point; it was assumed that the capacity of a plant to produce metal A multiplied by the

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[21] E. Colleran and A. Fothergill, "Capital Coefficients for the Nickel Smelting and Refining Industry," Bureau of Mines, Inter-Industry Analysis Branch Item 41, processed, January 15, 1954.

density of metal A equals the capacity to produce metal B multiplied by the density of metal B. This assumption means that a rolling and drawing plant utilizes the same capital equipment regardless of the metal being processed and that the relationship between the capacities to produce any pair of metals, or the relationship between the respective capital coefficients, is determined by the ratio of the densities of the two metals. Our analyses indicate that some substitutions among metals can take place with only slight changes in equipment. For both rolled and extruded products the copper and aluminum coefficients were multiplied by their respective densities and an arithmetic mean of the two was taken for each coefficient. The coefficients then show the capital requirements per ton of capacity for a metal having a density of 1.00 gram per cubic centimeter. These coefficients were then converted to coefficients representing the particular metals in this industry by applying the average weighted density of ten metals in this group as a conversion factor. It is admitted that this use of densities (or ratios of densities) is a makeshift, albeit one with a logical basis. We should be most happy to substitute actual plant observations and calculations thereon for the figures derived by this procedure.

Iron Ore[22]

Coefficients were derived for this industry from the records of two World War II plants, neither one of which is typical of the mining methods associated with the Mesabi Range. Both observations were underground mines, and one of them was a high cost project. Unfortunately observations were not available on typical open pit mining operations such as might be expected to occur in expansions in Labrador, Venezuela, or Brazil. About the most that can be said for these coefficients is that they are at the upper end of the range of cost for open pit mining and are almost certainly below those required for the exploitation of the taconites.

Cement[23]

The sample plants in the cement industry consisted of thirteen observations, five of which were new plants and eight additions to

[22] T. Mayer, "Capital Coefficients for the Iron Ore Mining and Milling Industry," Bureau of Mines, Inter-Industry Analysis Branch Item 39, processed, October 23, 1953.

[23] V. Wertheimer, "Capital Coefficients in the Cement Industry," Bureau of Mines, Inter-Industry Analysis Branch Item 22, processed, February 15, 1953.

existing plants. In the final analysis one of the new plant observations was completely omitted from consideration since there were definite indications that the capacity was overstated (perhaps reflecting the optimism of the entrepreneur when making out his application for accelerated amortization). Probably more than any other industry in this study, the cement industry typifies the (atypical) case of a single product and a single production method. Nevertheless even this statement must be qualified; Portland cement may be produced by either the wet or dry process depending upon the raw material involved. Although two major sources of interplant variation in coefficients are removed from consideration, the remaining variation is discouragingly large. Some of it could be traced to differences in purchasing practices, to differences in prices paid for capital equipment, and to apparent errors in the estimate of capacity. Adjustment to account for the influence of factors such as these were made prior to the derivation of the final set of industry coefficients.

Bituminous Coal[24]

The coefficients in this industry were derived from a sample of eight plant observations of underground mines using the room and pillar method. In all respects the observations are representative of the most modern, fully mechanized operations in general use in the early years of World War II, including the crushing, washing, dewatering, drying, and sizing of the coal. The coefficients are not applicable to strip mining operations nor do they reflect the changes in capital equipment which have occurred as the result of the introduction of the continuous wall miner. In each case capacity refers to the maximum output per year assuming 2 shifts a day, 280 operating days a year, and adequate maintenance and repairs. Within these limitations, the capital coefficient is representative of balanced expansions in the bituminous coal industry.

Nonferrous Foundries[25]

Three groups of products were distinguished in the calculation of capital coefficients for this industry. Calculations were made for

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[24] A. Fothergill, "Capital Coefficients for the Bituminous Coal Industry," Bureau of Mines, Inter-Industry Analysis Branch Item 35, processed, September 12, 1953.

[25] M. Ingbar, "Capital Coefficients for the Nonferrous Foundry Industry," Bureau of Mines, Inter-Industry Analysis Branch Item 34, processed, October 22, 1953.

sand castings, die castings, and permanent mold castings. In this, as in the rolling and drawing industries, the problem of defining capacity was solved by using a single metal as the unit of measurement and by expressing the capacity relationship between pairs of metals by the ratio of their densities. Any given product mix of, say, copper, aluminum, and magnesium sand castings can be expressed by weighting the coefficients for the individual metals in an appropriate manner. For example the 1947 product mix for sand castings was derived from data on tonnage shipments and the weights used were: magnesium sand castings, 0.01; copper sand castings, 0.85; aluminum sand castings, 0.14.

It should not appear that the use of ratios of densities as conversion factors, in this or the rolling and drawing industries, solved all of the problems in the measurement of capacity; it solved at most one problem—product mix. In this industry it was necessary to consider the effects of such factors as the amount of shelf items produced, the size, weight, and conformation of the castings, and the product mix among the different types of castings (as contrasted with the product mix of metals within a single type of casting). If separate coefficients can be calculated for different product types and if the product mix of metals within each type can be adequately handled, in all probability the context of the problem will indicate the weights which are to be used in combining these sets of coefficients. In brief that is the procedure which has been utilized in this industry.